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Claims

1. A mixed-mode fuel injector~~, which is a high accuracy couple of components~~ comprising:

(i) a nozzle body (5)~~, which has fuel~~ comprising passages for fuel~~, which has~~, an inner cylindrical spaces for receiving a ~~movable part~~ needle valve, and a conical surface (C) close to the tip (7) of the nozzle body for guiding a spray of fuel;~~,~~

(ii) a needle valve (1), which has a converging-diverging conical head ~~thereby~~for ~~guides the flow of~~ guiding a spray of fuel ~~,~~and which is movable back and forth and received in said nozzle body, wherein said needle valve is at a biased closing position or an opening position defined by driving means; and~~,~~

(iii) a micro-variable-circular-orifice (4) comprising a variable circular ring aperture between said needle valve and said nozzle body ~~and a plurality of micro-channels,~~

~~wherein~~ such that ~~it has means of discharging~~ fuel is dischargeable in variable sprays of conical and conical-multi-jet shapes through said micro-variable-circular-orifice by lifting said needle valve at different magnitudes.

2. A mixed-mode fuel injector according to claim 1, wherein the micro-variable-circular-orifice (4) further comprises a plurality of micro-channels (6).

~~2. A fuel injector, which is a high accuracy couple of components comprising: (i) a nozzle body, which has fuel passages, which has inner cylindrical spaces for receiving a movable part, which has a conical surface close to its tip for guiding fuel sprays, (ii) a needle valve, which has a converging diverging conical head thereby guides the flow of fuel, which is movable back and forth and received in said nozzle body, wherein said needle valve is at a biased closing position or an opening position defined by driving means, (iii) a micro variable circular orifice comprising a circular ring aperture between said needle valve and said nozzle body, wherein it has means of discharging fuel in variable sprays of conical shapes through said micro variable circular orifice by lifting said needle valve at different magnitudes.~~

3. A mixed-mode fuel injector~~The fuel injector of~~ according to claim 1 or 2~~-~~, wherein ~~close to the tip surface of nozzle body there is a conical surface for guiding fuel sprays,~~ the conical surface (C) ~~can be~~ has a single conical surface.

4. A mixed-mode fuel injector according to claim 1 or 2, wherein ~~,~~the conical surface (C) is an integrated conical surface ~~with~~ having two or more conical surfaces with different conical angles connected together.

Received at the EPO on Mar 31, 2008 17:55:28. Page 7 of 11

5. A mixed-mode fuel injector according to claim 1 or 2, wherein the conical surface (C) is ~~, or~~ a diverging curved surface.

64. A mixed-mode fuel injector according to claim 1 or 2~~The fuel injector of claim 1~~, wherein the needle lift for the opening position is approximately in the range of 0-300μm, the needle head diameter is approximately in the range of 0.8-3.5mm, and the angle between the centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degrees.

75. A mixed-mode fuel injector according to claim 2, ~~The fuel injector of claim 1 has~~ wherein the a plurality of micro-channels (6) is on the said conical surface (C) with ~~the~~ cross sections that are ~~shape of~~ one or more of semi-circles, arcs, triangles, trapezoids or other polygons.

8. A mixed-mode fuel injector according to claim 2, ~~,~~ wherein the needle head (3) remains at least partially received within the tip (7) as the needle valve (1) is moved back and forth between the biased closing position and opening position ~~the needle head is partially or fully merged in the tip surface of the nozzle body during the needle lifting, when the needle valve is lifted,~~ such that when fuel is injected through the micro variable aperture (4) between the needle head and said conical surface of the nozzle body, fuel is also injected through the multiple micro-channels (2), the upper surface of the needle head and the conical surface~~(s)~~ serve as guiding surfaces for fuel sprays.

96. A mixed-mode fuel injector according to claim 7~~The fuel injector of claim 5~~, wherein there are about 4-20 micro-channels (6) with the cross-section ~~shape of either~~ semi-circles with the diameters approximately in the range of 50-300μm.

10. A mixed-mode fuel injector according to claim 7 wherein ~~, or other shapes as described in claim 5~~ there are about 4-20 micro-channels (6) having a cross-section other than semi-circles with the maximum dimension approximately between 50-400μm.

11. A mixed-mode fuel injector according to any of claims 2 to 10, wherein the sizes of said micro-channels (6) ~~can be~~ are the same.

12. A mixed-mode fuel injector according to any of claims 2 to 10, wherein the sizes of the micro-channels (6) are ~~or~~ different depending on specific needs of atomization.

13. A mixed-mode fuel injector according to ~~any~~ of claims 2 to 12, wherein the said micro-channels (6) are distributed on or under the conical surface (C), ~~thus it~~ so that they ~~can be~~are open channels or closed channels.

14~~7~~. A mixed-mode fuel injector according to claim 2 has A fuel injector of claim 1 has a plurality of micro-channels underneath the said conical surface (C), ~~with the cross section shape of conventional nozzle holes, which can~~ forming a sac-hole or valve-covered-orifice multi-hole type injector through blocking the circular aperture by the needle head at a predefined needle-lift range.

15~~8~~. A mixed-mode fuel injector according to claim 2, ~~The fuel injector of claim 1 has means of generating~~ wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) , ~~wherein~~ and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and nozzle body (1), thus mainly forms a conical shape spray, while at high injection loads, fuel is injected through both the variable circular aperture between the needle head and nozzle body and the micro-channels (6), thus forms a mixed-mode conical-multi-jet shape spray, whereby provides different atomization desired by engine combustion at different loads.

16~~9~~. A mixed-mode fuel injector according to claim 2, ~~A fuel injector of claim 1 has means of generating~~ wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, ~~wherein~~ at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and nozzle body, thus mainly forms a conical shape spray, while at high injection loads, the needle head can completely or partially block the variable circular aperture, whereby fuel is fully or mainly injected through the micro-channels (6), which can be open channels or closed channels depending on penetration needs, thus mainly forms conventional multi-hole sprays at high loads, whereby provides different penetration desired by engine combustion at different loads.

~~10. The fuel injector of claim 2, wherein close to the tip surface of nozzle body there is a conical surface, the conical surface is of a single conical surface, an integrated conical surface comprising two or more conical surfaces with different conical angles, a diverging curve surface, the upper rim of the head of the needle valve is merged in the tip surface of the nozzle body during the needle lifting, when the needle valve is lifted, fuel is~~

~~injected through said micro variable aperture between the needle head and conical surface of the nozzle body.~~

17~~11~~. A mixed-mode fuel injector according to claim 1 or 2~~The fuel injector of claim 1 or claim 2~~, wherein the fuel channel between the needle valve (1) and the nozzle body (5) is of converging-diverging shape and, by lifting said needle valve at different magnitudes, the minimum cross-section is at the sealing surface during the early stage of fuel injection, the minimum cross- section is at said micro-variable-circular-orifice (4) or at the sealing surface during the middle stage of fuel injection, and the minimum cross-section is at the sealing surface again during the late stage of fuel injection, whereby it has means of ensuring fine atomization during all fuel injection stages.

18~~12~~. A mixed-mode fuel injector according to claim 1 or 2~~The fuel injector of claim 1 or claim 2~~, wherein the angle between the centerline of the conical surface (C) and the centerline of the nozzle body (5) is approximately 0-15 degrees, depending on an~~the~~ angle between a~~the~~ centerline of the fuel injector and ~~the~~ a centerline of ~~the~~ a piston in ~~the~~an engine cylinder.

19~~13~~. A mixed-mode fuel injector according to any of the preceding claims~~The fuel injector of claim 1 or claim 2~~, wherein the ~~fluid~~ fuel injected ~~can be~~ is one or more of diesel fuels, gasoline fuels, alternative fuels, mixtures of water and fuels, pure water, or liquid exhaust cleaning additives~~, whereby~~ in which case, the fuel injector is a~~serves as a~~ general purpose injector.

20~~14~~. A mixed-mode fuel injector according to claim 1~~A fuel injector of claim 1 or claim 2~~, wherein the needle valve (1) is passively driven by high fuel pressure, ~~whereby~~ which provides said driving means.

21~~15~~. A mixed-mode fuel injector according to claim 1~~A fuel injector of claim 1 or claim 2~~, wherein the needle valve (1) is actively driven by an actuator which provides said driving means.

22. A mixed-mode fuel injector according to claim 21, wherein the ~~which can be a~~ actuator is a solenoid or a piezo actuator, ~~whereby provides said driving means.~~

23~~16~~. A mixed-mode fuel injector ~~A fuel injector~~, which has a micro-variable-circular-orifice (MVCO) comprising a variable circular ring aperture and multiple-micro-channels

as in claim ~~1~~2 , wherein the MVCO is used as a sole orifice or in-combination with other multi- hole conventional orifice.

~~17. These are skilled in the art will find that it's easy to make minor changes to the nozzle structure following the same principle illustrated in this invention, such as adding micro channels or adding spirals on the needle head or the conical surface of the nozzle body, wherein outer surfaces of the nozzle body can be of cylindrical, conical, or converging diverging shapes, whereby these ramifications are within the scope of this invention.~~